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APPLICATION OF IMRI'S SENSOR TECHNOLOGIES TO THE CANADIAN STEEL AND CASTING INDUSTRIES

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RAPPORT FINAL

APPLICATION OF IMRI'S SENSOR TECHNOLOGIES

PAR

E.W. LEAVER

POUR

L'INSTITUT DE GENIE DES MATERIAUX

AOUT 1987

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e.w. leaver, p.eng.

FINAL REPORT

Contract No. 985-5036
(Including Amendments)

Summary (Work)

This contract, entitled "Application of IMRI's Sensor Technologies to the Canadian Steel and Casting Industries", covered work by Eric W. Leaver in cooperation with IMRI, over the period from December 1985 through August, 1987.

The work included the compilation of a list of Canadian casting facilities including ferrous foundries, non-ferrous foundries and die casters. The list was completed and sent to IMRI on March 31, 1986.

A number of representative foundries and die casters were then selected in cooperation with IMRI for visits, initially by Eric Leaver, and later by Eric Leaver and Dr. Jean Bussiere. These visits included small and large facilities, and those involved with copper, brass, aluminum, zinc, iron, ductile iron, carbon and alloy steel, and stainless steel. The companies visited served the automobile, aerospace, process industries such as petrochemical and pulp and paper, as well as the general market. This work, and the conclusions drawn from it, were the subject of my report dated February 28, 1987.

The contract was amended January 9, 1987, to include work in the area of thin strip casting of steel. It included a literature search, visits to various companies involved in similar work, attendance at various meetings on the subject with representatives of the CSIRA, IMRI, CANMET and universities. It also involved the preparation of my contribution to a joint paper with Dr. Jean Bussiere on sensors and controls for strip casting. This paper was presented in May, 1987 to the CIM meeting in Hamilton by Dr. Bussiere. A copy of my contribution is included as an Appendix to this report.

A substantial sum of the funds allocated to this contract remains unused. A major factor in this situation was that visits planned to some companies in the United States and Europe become impractical. The information sought was not available.

A planned conference visit to The U.S. became unnecessary because its agenda became available at a meeting held in Toronto in May. This latter meeting was attended by me. Even though, many of the planned visits could not take place, the required information was obtained and reported in our paper mentioned above.

At a final meeting with Dr. Bussiere at IMRI on August 11, 1987, it was agreed the work had been completed and the contract would end as contracted on August 31, 1987.

Summary (Discussion and Conclusions)

The objectives of a study such as this may include; the areas of IMRI's interests and capabilities, the needs of the chosen industries that overlap the IMRI areas, and finally the directions IMRI's future activities might take. The first phase of the contract dealt with IMRI and an established industry and mature processes, the second with an industrial process yet to be created.

With regard to the first phase of the work, the problems amenable to IMRI involvement, by necessity, must be those common to a number of companies rather than a single one. Further, the problems must not just involve straight forward, short-term engineering but research and development.

The sensor activities of IMRI with which this contract was concerned, mainly involved the application of ultrasonics, magnetics, eddy-currents, and optics,(including lasers). IMRI has considerable experience in these areas and appropriate facilities to perform experiments to determine the practicality of various industrial applications.

The companies visited had many problems which could be addressed by the development of sensors utilizing IMRI technologies. These included the on-line and off-line detection and/or measurement of product properties, and defects such as hardness, depth of hardness, internal structure, (including dendritic arm spacing), surface and internal quality, (including cracks and voids), surface temperatures, (independent of emissivity), dimensions, (including coating thicknesses), and geometry.

Many of these problems were those requiring an immediate individualized solution, and while important, could not be undertaken by IMRI. They indicated a shortage of engineering personnel in some companies, and in the case of some of the smaller companies, possibly a lack of funds to employ them. Even in some of the larger firms, the short-term nature of some of the problems is shown by the companies' changing level of interest in specific problems and the migration of interest from one problem to another over short periods of time.

Nevertheless, there were common problems, some of which have been the focus of IMRI's subsequent experimental work. These problems include the measurement of hardness and depth of hardness for a wide variety of products, on-line and off-line.

Physical properties, including tensile strength and formability were found to be of considerable interest, both for on-line and off line, for the steel strip and casting industries. The detection of voids and cracks in such difficult materials to inspect as copper castings, is still a problem in spite of the long history of ultrasonic inspection.

Accurate temperature measurement is still a problem in many industrial processes, even though there are many sensors on the market. Emissivity variations, ambient conditions, and some required ranges of temperature measurement, are largely unsolved problems. The situation has been made more urgent by the increasing demand for accuracy brought about by the ever higher quality needs. Some new approaches seem to be required, i.e. some fairly basic research.

IMRI's work with lasers and ultrasonics could find numerous industrial applications, if the equipment could be made mill-worthy, and applied to such sensor problems as on-line measurement of dimensions, bulk temperature and/or detection of flaws in hot products.

The work involved with the CSIRA/IMRI/CANMET thin strip project, included a literature search, visits to Hazelett and Noranda and concentrated on the anticipated requirements for sensing and control for the new process.

It seems evident that accurate, multi-point continuous temperature measurement and control will be necessary in the commercial embodiment of the process. Further, sensors for the detection and control of the solidification point(s), and accurate on-line guaging of the hot product will be required. All of these will require research and development.

In addition, an over-all control system based on mass and energy flows and balances as well as on a viable strategy, will be required for commercial implementation of the process. Start-up, in-process changes, shut-down and even on-going production, needs such a system to bring these operations within the skills-span of the normal operator. Such systems will intimately depend on the sensors available to supply the required information accurately, and quickly in a form suitable for human interfacing.

APPENDIX

Control and Sensor Requirements

for a

Strip Casting Line

Control and Sensor Requirements for a Strip Casting Line

Eric W. Leaver
4001 Bayview Avenue, Suite 304
Willowdale, Ontario, M2M 3Z7

and

Jean F. Bussière
National Research Council Canada
Industrial Materials Research Institute
75 de Mortagne Blvd.
Boucherville, Québec, J4B 6Y4

Abstract:

Over the last several years the success of the continuous casting process in terms of energy savings, productivity and quality, has not only been the result of improvements in the process itself but also, and in no small way, the result of improvements and intensity of application of sensors and controls. Because of narrower operating windows, the direct casting of high quality thin strip is expected to be even more demanding in respect to the necessary sensors and controls.

Much of the control strategy, architecture and control loops can be directly applied to strip casting. These will be described and illustrated, drawing on state-of-the-art systems installed in Japan. In addition to the need for tight control of speeds, temperatures, surface quality, etc., the direct casting of strip could benefit from the introduction of new sensors for monitoring solidification and locating solid/liquid interfaces. Such sensors, together with their possible implementation and control in a strip caster, will be discussed.

CONTROL REQUIREMENTS FOR STRIP CASTING LINE

Eric W. Leaver

March 22, 1987

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CONTROL AND SENSOR REQUIREMENTS FOR A STRIP CASTING LINE

GENERAL:

Over the last several years the burgeoning success of the continuous casting process in terms of energy savings, (Ref.1), productivity and quality, has resulted not only from improvements in the process itself, but in no small way upon the improvements and intensity of application of sensors and controls over the years since its introduction.

We believe the direct casting of high quality thin strip will be even more demanding in respect to the necessary controls than conventional continuous casting because it will probably have to contend with an even narrower "operating window". For these reasons we recommend instrumentation of the processes by means of the most direct methods with the most appropriate sensors available. Then we would recommend the use of microprocessors in conjunction with the sensor inputs and the best process models to provide local control of the unit processes. These would be co-ordinated and supervised by an executive program in a higher level computer which would provide over-all system monitoring and control. This system would be valuable not only in aiding the process work satisfactorily, but in validating the experimental results, indicating the best paths toward improvements, and assisting in scaling-up the development and prototype processes.

In the following discussions we look at not only the forming process itself which will most probably be the main area of development, but the production unit in which it will most likely be embedded in a commercial application. While the overall concept would eliminate the roughing mill of conventional hot strip mills, it seems unlikely that all finishing operations should be dispensed with, even if they are reduced. It seems probable that the sensing and control requirements may be somewhat different than those of conventional mills. Also, they may be more demanding in some respects and less so in others. In this proposed process for example, continuous production over considerable periods may be practical, so that the rapid changes experienced due to discontinuous bars with the head to tail and bar to bar variations common to conventional hot strip mills, would not occur. These variations are responsible for many of the problems and complexity of control of hot strip mills.

As for the control of all complex systems, we must begin with consideration of the desired control stategy, and then the control architecture which can implement that strategy.

CONTROL STRATEGY:

The overall system is comprised of a number of processes which may be considered by themselves as semi-independent systems. Therefore the most suitable strategy is to have them controlled as much as is feasible on a local basis, i.e. short loop control for some of their respective variables.

On the other hand, the processes are intimately linked, the output of one unit being the direct input of the next. Further, feedback is required for several loops over two or more local processes, in the form of long loop control. Thus provision must be made for overall system coordination and control. Such overall control will be subject to manual set-point controls consistent with the overall process objectives, e.g. product thickness, product flatness, surface quality production rate, etc..

CONTROL ARCHITECTURE: (Fig. 1)

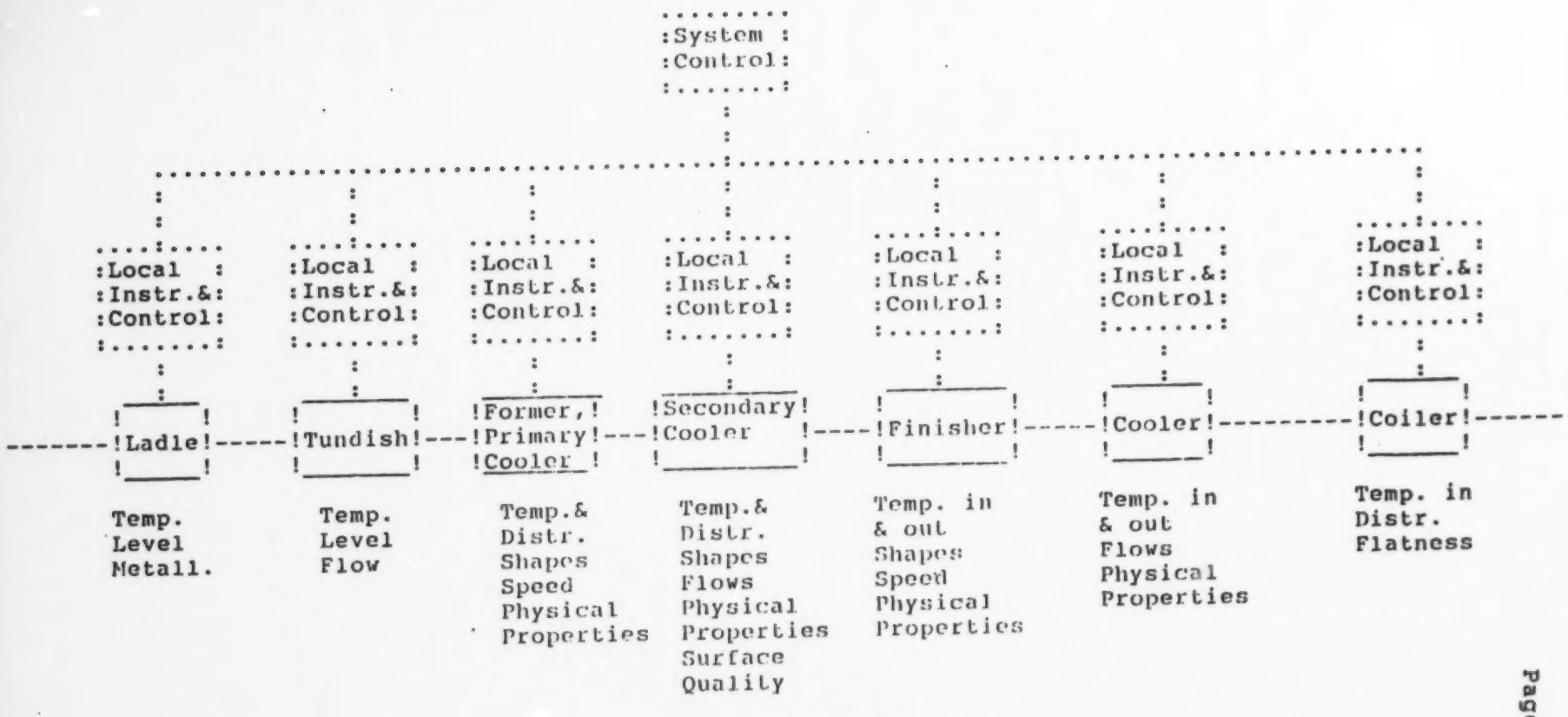
System Computer

In the overall system computer, there would be:

i. An executive
ii. Overall system models, dynamic and steady-state mass and heat balances
iii. Engineering inputs
iv. Direct sensor inputs
v. Direct control outputs
vi. Sensor/control local loop supervisory inputs
vii. Supervisory control outputs
viii. Operator inputs
ix. Display outputs
x. Printer output

This computer and some of its software would be very valuable in the design phase of the project, before and during the construction phase of the pilot plant.

The overall system models ii., and detailed unit models would be developed as part of the design process, and could be used to validate many of the design concepts before physical construction. These approaches are now widely accepted in many process industries, and should, we believe, receive serious consideration for this project.



"Shapes", one or more of:

- Guage & profile
- Width
- Flatness

Fig. 1. - Overall System Control Aspects - Strip Casting Project

CONTROL ARCHITECTURE (continued)

Local Sensor/Control Microprocessors

In addition to some direct sensor and control links to the system computer, some of the various unit processes such as the Ladle, Tundish, Former, etc., will have their own local control microprocessors involved only with the sensors and controls dedicated to the operations of those individual units. In addition, however, they will also communicate to and receive instructions from the system computer described above.

POSSIBLE CONTROL LOOPS:

Some of the control loops which may be required are as follows, (The precise number and make-up will, of course, depend on the processes and their configurations finally chosen);-

1. Ladle:

   i. Molten steel treatment control
   ii. Temperature measurement/control
   iii. Flow issuing control
   iv. Slag issuing detection/control

2. Tundish:

   i. Temperature measurement/control
   ii. Weight/level measurement/control
   iii. Flow issuing measurement/control

3. Former:

   i. Temperature, distribution, measurements/controls
   ii. Level measurements/controls
   iii. Speed measurement /control
   iv. Metal flow distribution, measurements/controls
   v. Critical physical properties detection, measurements/controls
   vi. Cooling flows, measurements/controls

4. Secondary cooler:

   i. Temperature, distribution, measurements/controls
   ii. Cooling flows, distribution measurements/controls
   iii. "Shapes",* measurements/controls
   iv. Critical physical properties measurements

POSSIBLE CONTROL LOOPS (continued)

5. Finisher:

   i. Temperatures in and out measurements
   ii. Speeds, in, and out measurements/controls
   iii. "Shapes",* measurements and controls

6. Run-out Table Cooler:

   i. Temperatures, distribution measurements ----------,
   ii. Cooling flows, distribution measurements/controls--1
   iii. Physical properties, phase transition detection
                                                          1
7. Coiler: 1
                                                          1
   i. Temperature in distribution measurement/control----'
   ii. Flatness sensor-----------------------------------'

Notes: The above outline of measurement and control requirements may include some redundancies, e.g. temperatures out of one unit process and in the next. The extent of the redundancies depend on the final configuration chosen.

*"Shapes",- one or more of gauge & profile, width, flatness.

DISCUSSION:

Irrespective of the forming process chosen for the project, it is probable that variables such as temperature, flows and ferrostatic heads, (levels), physical constraints and speeds, must be very closely controlled. Further, it is also probable that their inter-relationships should also be very tightly co-ordinated. It is for these reasons that we recommend the use of the hierarchical system, the use of steady-state and dynamic models and steady-state and dynamic mass and heat balance calculators, and the local controls configurations outlined above.

In regard to temperature, for example, the Tundish may require heating controlled directly from its own temperature sensor(s), and indirectly through appropriate circuitry by feedforward from the ladle temperature sensor. and feedback from temperature sensors at the Former. The conditions obtaining in present day "formers", (molds), and secondary cooling have proven critical to the attainment of acceptable production rates and quality of product. The projected process may be even more critical. Hence temperature distribution control in the cooling zone will involve similar precise measurements and direct control as well as feedback and feedforward features. Such controls will require appropriate models to take time delays including transit times, and bulk effects including thermal lags into account.

DISCUSSION (continued)

In regard to flows, throttling valves and ferrostatic heads above the Former will have to be precisely controlled. One variable will be Tundish level. This will be determined by outflows to the Former and inflows from the Ladle. Thus we will be faced with a rather complex inter-related system which must respond suitably and precisely to the inevitable fluctuations in the processes.

Take-away speed at the Former will obviously not only have to be precisely controlled, but must be rigidly phase-locked.

One of the process variables will have to be chosen as the reference or control variable. It may be product thickness, or a quality or production rate etc.

Other important factors are the dynamic conditions attendant on start-up, grade change and shut-down.

In considering the general philosophy of the control strategy and architecture proposed in the preceding pages, we believe that Fig. 2., which illustrates the Sumitomo Slide Gate System for automatic mold level control, (Ref.2) and Figure 3., which is is a block diagram of the computer control used in a Japanese continuous caster, (Ref. 3), will be indicative of some of the requirements for the strip casting project.

As we mentioned above, later parts of the process may be less critical than those directly associated with the Former, but nevertheless, quality products can only rarely be produced consistently without close control. Present trends indicate quality products will be the only products acceptable in the market-place likely to exist when this process becomes commercial.

For comparison purposes, an example of an hierarchical control system used in the control of a conventional continuous caster in Japan is shown in Table 1. See Ref. 4. Many of the considerations involved in the design of this system will still obtain regardless of the final configuration chosen for casting thin strip. Controls for the modern continuous caster have evolved over the years to where they now make significant contributions to the present levels of productivity, consistency and quality of product. We anticipate a similar evolution with like results for the control systems for strip casting.

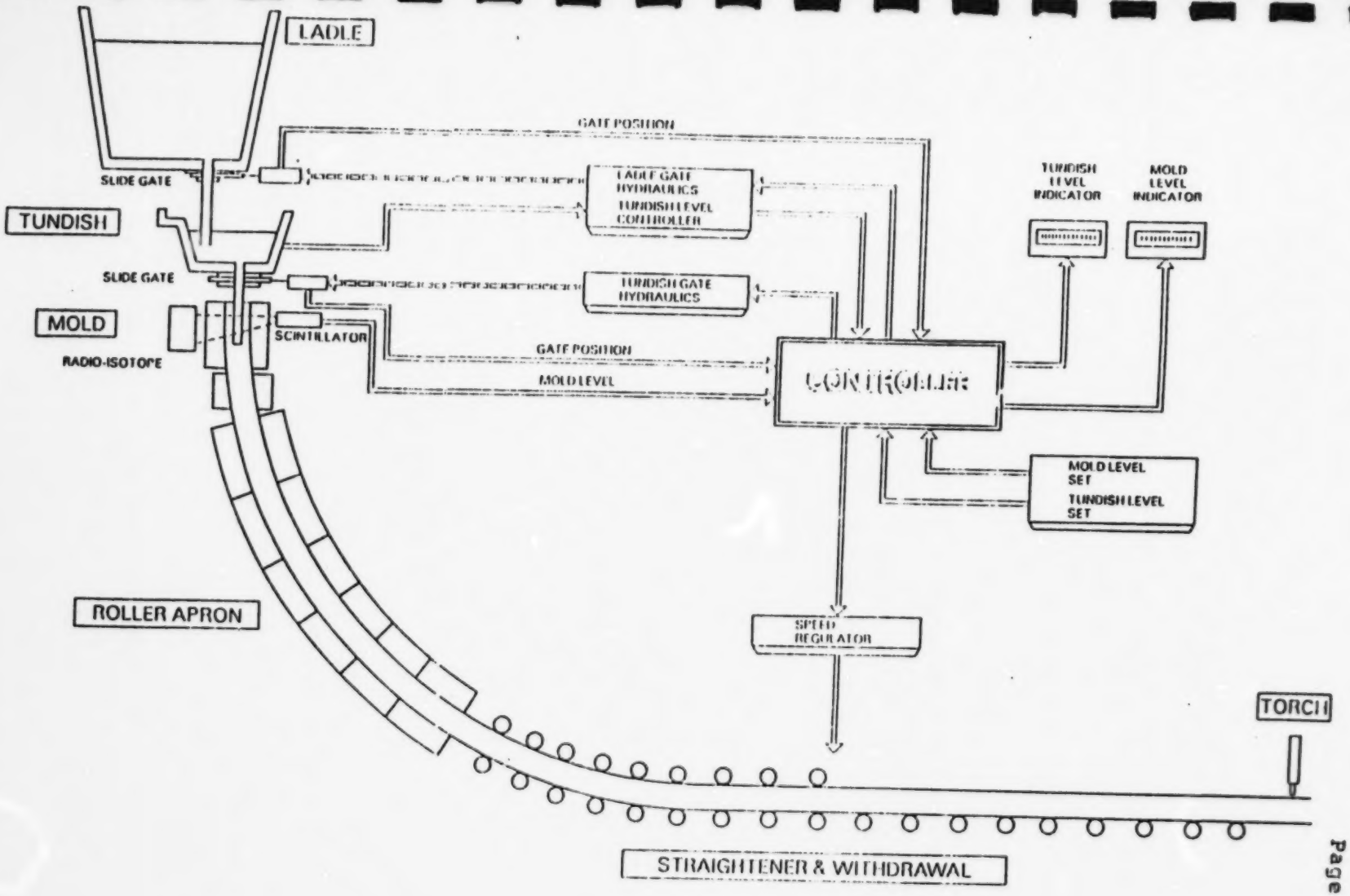


Fig. 2. Automatic Mold Level Control

Fig. 3. Computer Control of Continuous Caster

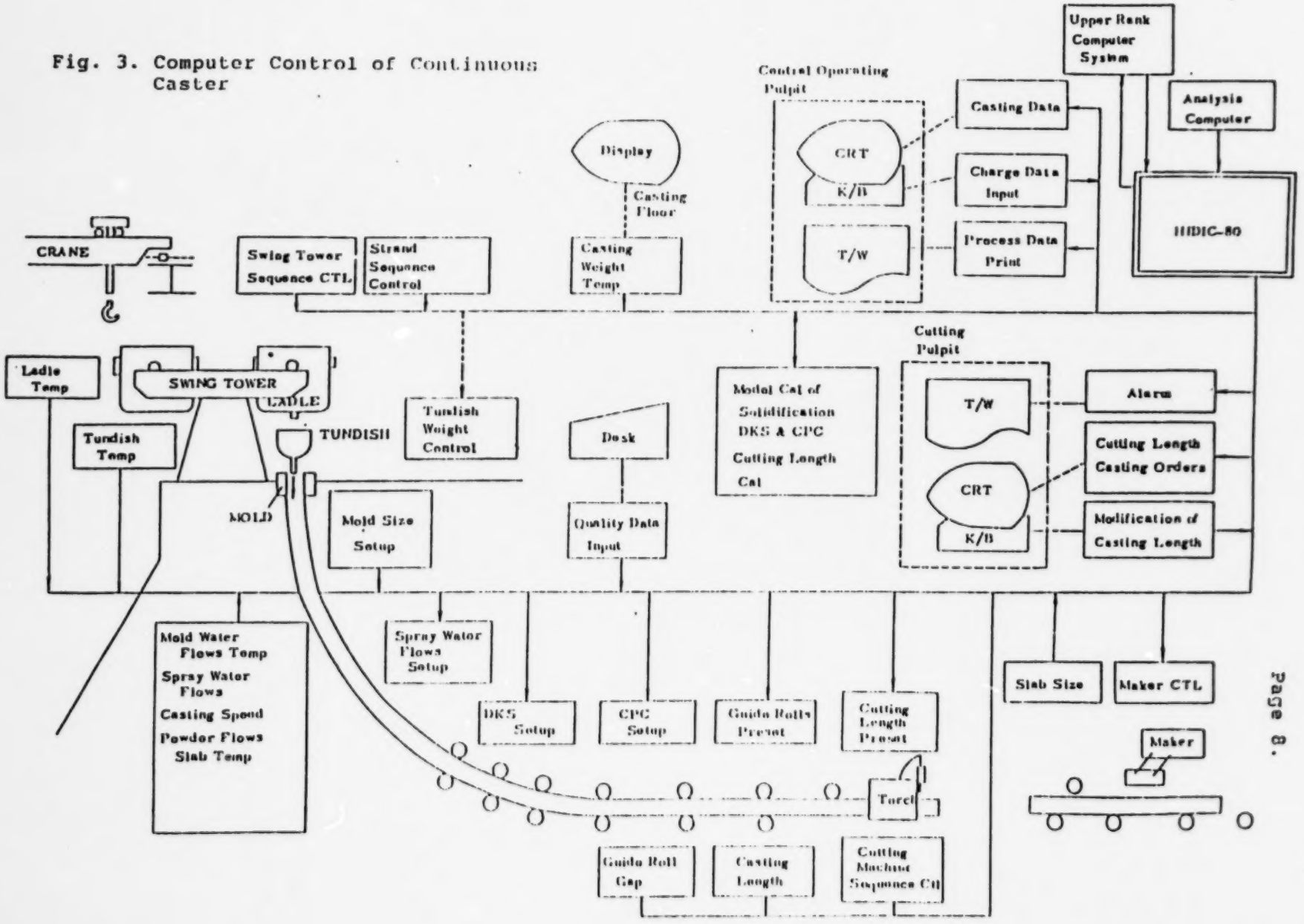
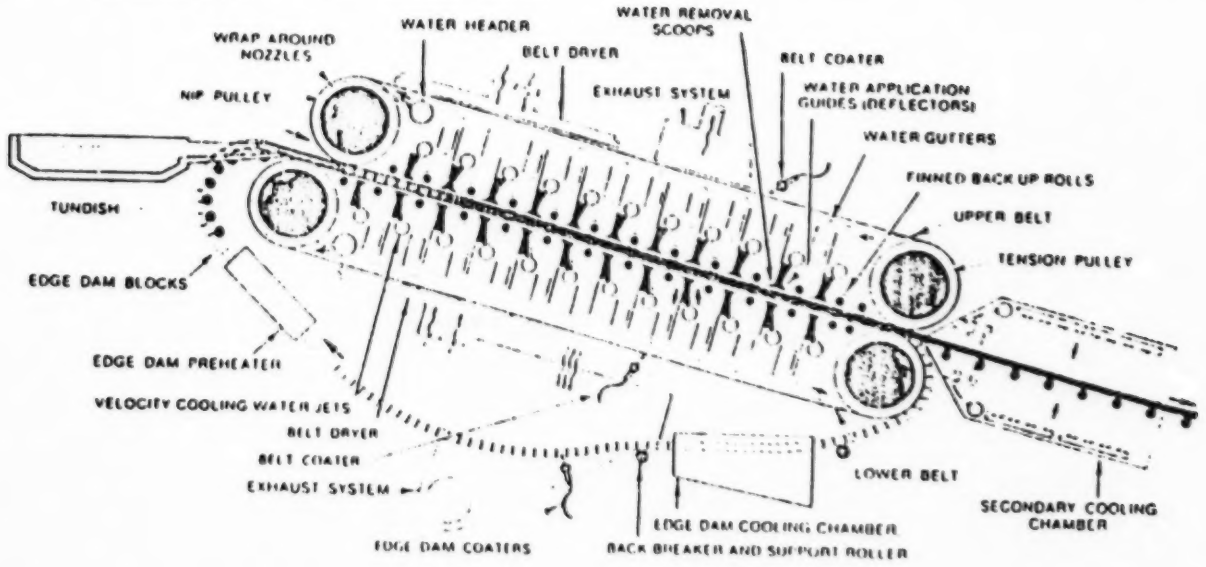


Table 1 Hierarchial Control Example in the CCP

	Function	Loop Controller	Process Console	Sequencer	Process Computer
Ladle (LD)	• Weight measuring	• Measuring sequence	• Status indication • Weight indication • Molten steel temperature indication		
	• Temperature measuring	• Measuring sequence			
Tundish (TD)	• Weight Control	• Optimum control • Mean weight change rate correction • Automatic start, stop	• Status indication • Process data indication • Process operation • Manual instruction for parameters		• Parameter setting
	• Temperature measuring	• Measuring sequence			
	• Free oxygen measuring	• Measuring sequence			
	• Oxygen control in TD atmosphere	• Argon sealing control			
Mold (MD)	• Level control	• I-PD control algorithm • Automatic start/stop • SN position/casting speed override control • SN characteristics correction • Auto/manu bumpless switchover • Alarm for overflow/breakout prevention	• Status indication • Process data indication • Process operation • Manual instruction for parameters		• Parameter setting • Heat extraction calculation
	• Cooling water control	• Automatic flowrate correction by casting speed • Alarm for insufficient heat transmission			
Strand (ST)	• Air-mist cooling control	• Automatic water flowrate/air flowrate or air pressure control by casting speed • Transient treatment for lot size change • Heat hand tracking • Flowrate distribution • Pulsation spray control • Shut-off valve control • Nozzle clogging calculation	• Status indication • Process data indication • Process operation • Manual instruction for parameters • Display of spray pattern • Solidification status indication • Major parameter table maintenance • Nozzle clogging display		• Solidification model calculation • Parameter setting according to operational condition • Automatic parameter correction by model calculation • Instruction for transient processing when operational conditions are changed.
	• Cooling water primary pressure control	• Override control of pump speed/pressure control valve position			
Total Length	• Casting length measurement		• Total length/remainder length indication • Cutting data indication	• Full length tracking • Indication and alarm of total length • Switchover of measuring pulse generator • Instruction for cutting	• Parameter setting • Position tracking for operation control
Cutter/Stamper	• Cutter control			• Control of torch position/speed • Control of torch car position • Stamper code control	• Parameter setting
	• Stamper control				
Other		• TD preheat control by heat pattern	• Status indication • Manual instruction for parameters	• Dummy bar control	• Parameter setting • Guidance for various operation • Logging/reporting
		• Roll gap measurement			

Fig. 4.- Schematic diagram of twin-belt, bar casting system.



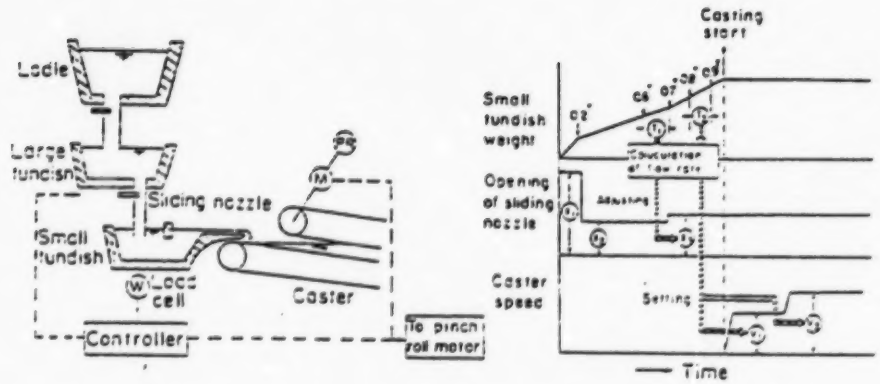


Fig. 5.- Automatic caster start-up system.

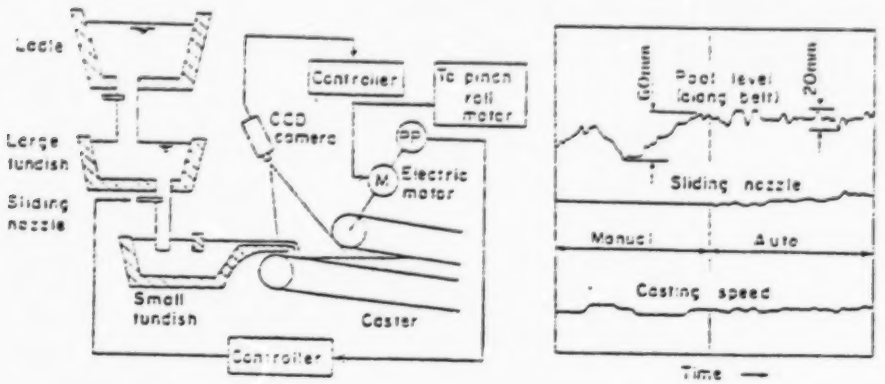


Fig. 6.- Automatic pool level control system.

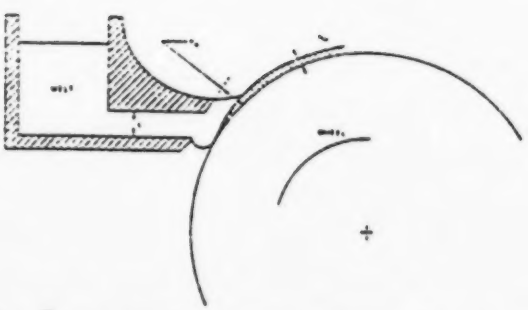


Fig. 7.- Schematic of Single-Roller Casting System

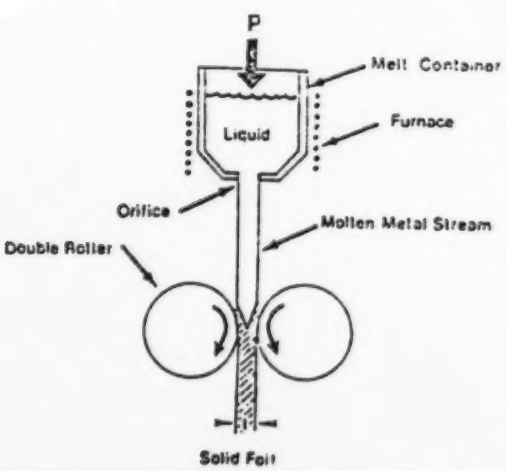


Fig. 8.- Schematic Illustration of Double-Roller Process

POSSIBLE PROCESS CANDIDATES, AND THEIR CONTROLS:

As far as one can determine from the literature, there is no presently existing process producing steel in the thickness ranges targetted for this project. There are, however, at least three processes which conceivably could be adapted and developed to fill this requirement. These are:

1. The Hazelett twin-belt caster (Fig. 4, Ref. 5)
2. The single-roller caster (Fig. 7, Ref. 1)
3. The double-roller caster (Fig. 8, Ref. 1)

The Hazelett twin-belt caster approaches the problem from the thick end, i.e. thin slab. The other two approach it from the thin strip extreme. We believe it useful to look at some of the considerations involved in the control of their perceived critical variables. For examples of these processes, we will look at three recent papers on the subject, References 5., 6. and 1..

Sumitomo Hazelett Caster

The control arrangements for automatic start-up and automatic pool level control for a thin slab caster at Sumitomo's Kashima works is shown in Fig. 5. and Fig. 6. (Taken from Ref. 6).

The Former, consists of a small Tundish feeding a pool which in turn feeds the casting belt cavity. During automatic start-up of the system, the pouring rate and caster speed are automatically adjusted to the target value. The caster speed is then calculated and set to match the appropriate casting rate. Initially, the pouring rate from the large Tundish to the small Tundish, which is controlled by a sliding gate nozzle, is controlled and set by the small Tundish level. The latter is measured indirectly by load cells.

During steady state casting, other controls are required to maintain stability. One of these is a CCD camera to constantly monitor pool level, and by appropriate controllers, maintain it at a suitable value by making adjustments to the sling gate nozzle, caster speed control system.

According to engineers at a different site where a Hazelett caster is used to cast copper bar, the critical variables for their caster are,- metal temperature, levels, speed, water flow and water temperature.

Single-Roller Caster

An arrangement for a single-roller caster is shown in Fig. 7. (Taken from Ref. 1). The paper states that the stand-off distance, head height, wheel speed and melt pressure, are all important in determining strip thickness and hence, by inference must be closely dynamically controlled. Temperatures are less important in this caster in thickness control, but are important in determining quality.

Double-Roller Caster

This may be the choice for the strip caster, because it may offer the best hope for achieving the target thickness range. A simplistic layout of such a Former is shown in Fig. 8. (Taken from Ref. 1).

The paper states that the wheel speed, puddle height, and pour temperature, are important in determining strip thickness. The substrate temperature is less important. The most important of all is the puddle height, so that would be one of the variables which would have to be closely and dynamically controlled.

SUMMARY:

We have attempted to outline a control strategy and architecture which should be considered for the control of what is most likely to be a difficult-to-control process. As the process has not yet been chosen, and hence not designed, it is impossible to be specific as to how it is to be controlled. We mention briefly some of the important criteria for what may well be the closest approaches now extant to the target process.

In view of uncertainties which must necessarily surround the choice and design of a radically new process, we recommend reducing these uncertainties by using advanced design tools. These include the use of extensive computer modelling not only of the more critical process areas such as the yet-to-be-developed forming process, but the other processes as well and the utilization of an overall systems model. This work should be well underway before actual equipment construction takes place. Such a procedure could save much time and money in the design and debugging processes. In addition, it can provide the foundation for the control system which should be used in the prototype and following stages of the project.

In the past, the tendency was to believe that if a process was properly designed, little attention need be paid to control per se. Some industries have paid heavily for this mistake. Sophisticated control can provide more manageable "operating windows", and operating flexibilities, consistency and quality of product, not achievable in any other way. We therefore believe the control aspects should be considered as an important and integral part of the project from its inception to completion.

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